AD-A042 753 WASHINGTON UNIV SEATTLE APPLIED PHYSICS LAB F/G 20/1
ACOUSTIC PROPERTIES OF SEAWATER AT SUBZERO TEMPERATURES PHASE I--ETC(U)
JUL 77 R E BUNNEY, E A PENCE N00014-75-C-0844

UNCLASSIFIED APL-UW-7722 NL

1 OF 1

ADA042 753

END

DATE FILMED

9-77

DDC

12

ACOUSTIC PROPERTIES OF SEAWATER AT SUBZERO TEMPERATURES
PHASE I: EXPERIMENT DESIGN

R. E. Bunney and E. A. Pence

Applied Physics Laboratory
UNIVERSITY OF WASHINGTON
SEATTLE, WASHINGTON 98105

15 July 1977

Final Report, APL-UW 7722

Work supported by
Office of Naval Research
DEPARTMENT OF THE NAVY
ARLINGTON, VIRGINIA 22217

Contract No. N00014-75-C-0844

6

ACOUSTIC PROPERTIES OF SEAWATER AT SUBZERO TEMPERATURES

PHASE I: EXPERIMENT DESIGN

10 R.E. Bunney and E.A. Pence

Applied Physics Laboratory
UNIVERSITY OF WASHINGTON
SEATTLE, WASHINGTON 98105

12 24p.

11 15 July 1977

9 Final Report, 14 APL-UW-7722

Work supported by
Office of Naval Research
DEPARTMENT OF THE NAVY
ARLINGTON, VIRGINIA 22217

15 Contract No. N00014-75-C-0844 new

Approved for public release; distribution unlimited

031 700

LB

ABSTRACT

Field experiments[1] have indicated that transmissions of acoustic signals in seawater at or near its freezing point are subject to larger attenuation than predicted by existing theory. If verified, this effect should be of paramount importance to investigators operating acoustic devices in polar seas and cold deep water environments. A survey of the literature has failed to show previous experimental or theoretical studies for this temperature regime in seawater. A preliminary experiment was undertaken to (a) demonstrate the reproducibility of the field results in the laboratory; (b) design an acoustic experiment to measure the magnitude of the effect; (c) determine the cause of the anomaly; and (d) provide (at least empirical) equations to predict acoustic absorption/attenuation in cold seawater environments. This document reports the results of the preliminary study of items (a) and (b) above.

I. INTRODUCTION

Experiments during recent arctic field trips have shown that acoustic attenuation in this environment is significantly more pronounced than expected. Specifically, (a) during the original tests of the Underwater Arctic Research Submersible (UARS) at Fletcher's Ice Island T-3 in 1972, acoustic communication with the vehicle was frequently intermittent at ranges exceeding 300 yd, indicating anomalous acoustic characteristics in the medium; (b) transmission studies in the Chukchi Sea during 1974 indicated that the acoustic attenuation was significantly greater than predicted by existing theory using the relaxation of $MgSO_4$ as the mechanism of excess attenuation.

Particular systems whose application depends on the ability to transmit acoustic signals over significant distances include acoustic data link or command systems (such as that for the UARS), underwater tracking systems, search and navigational sonar systems, and various existing and proposed intelligence gathering systems. A preliminary literature review indicates that acoustic propagation in seawater with temperatures below 0°C has not been investigated, or at least has not been widely reported, even though these temperatures exist over large areas of the polar regions.

It is believed that the excess attenuation observed in this temperature region is probably caused either by the formation of fresh water microcrystals originating from disturbances or nucleation centers in the supercooled medium (each of which may act as a scattering center for the acoustic wave), or by a yet-to-be-explained temperature-dependent relaxation process. There is every reason to believe that crystallization formation conditions may occur in the polar oceans; such conditions have, in fact, been observed on at least one occasion.[1] The existence of microcrystals in the medium, because of their effects on the velocity and attenuation of an acoustic wave, can be as viable an explanation for the observed transmission peculiarities as freshwater lenses, and are more easily justified physically.

A basic research program was initiated to study, in the laboratory, the propagation of sound in subzero saline solutions as a function of temperature, salinity, and frequency. Based on the results of the pilot study, ONR funded the first phase of a two-phase investigation to: (a) provide a basic understanding of the mechanism of the excess attenuation in seawater at temperatures below 0°C, (b) provide a basis for the prediction of acoustic properties through theoretical and/or empirically

derived equations that relate the transmission characteristics as a function of temperature and frequency, and (c) provide design criteria for follow-on field experiments. Unfortunately, the experimental program was terminated before any conclusive understanding of the above items was achieved.

The purpose of this first phase was to study possible methods of measuring the anomalous absorption near the freezing point and, specifically, to design an acoustic experiment for the follow-on, experimental phase of the study. This document constitutes the final report of the Phase I investigation in accordance with the requirements of Contract N00014-75-C-0844.

II. REVIEW OF THE PRESENT STATE OF KNOWLEDGE

As previously mentioned, a review of the open literature has failed to disclose acoustic attenuation measurements in seawater at temperatures below 0°C, even though such temperatures exist over large portions of the polar seas and in deep water environments. Field tests and our laboratory study have shown that extrapolation of the results of measurements in more temperate seawater is inadequate to describe the propagation of sound in the lower temperature regime. Because the mechanism for the observed excess attenuation is yet to be understood, it is instructive to trace the development of this topic.

Stokes[2,3] published the first theoretical treatment on the influence of heat and internal friction on the propagation of elastic waves. According to this classical theory, sound waves in liquids suffer an energy loss owing to shear forces that is proportional to the square of the acoustic frequency. Because of the primitive measurement methods available to experimenters, even rudimentary verification of Stokes' theory was hindered for nearly 75 years, i.e., until the early 1920's. During the ensuing period, experimentation revealed that in nearly all liquids sound absorption considerably exceeded the classical value predicted by Stokes, thus indicating losses by other mechanisms. The causes of excess absorption were attributed to volume or pressure viscosity caused by retarded transition of energy between different degrees of freedom, to relaxation processes such as the excitation of rotational or vibrational degrees of freedom of molecules, to chemical reactions, to the change of molecules to interlattice positions in the quasicrystalline structure, to the dissociation of ions, etc.

The first acoustic pulse echo experiments were performed by Pinkerton[4] in 1947 and showed conclusively that Stokes' theory (that attenuation is linearly proportional to the frequency squared) must be modulated by a nonlinear temperature dependent term. The results of this experiment are shown in Figure 1.

A considerable numer of investigations determined the absorption of sound in gases and liquids to be proportional, but not equal in magnitude, to Stokes' theory. Liebermann[5] studied the attenuation of sound in the frequency range of 100-1000 kHz in both fresh and seawater and determined that in fresh water the observed variation with theory could be totally explained by viscous dissipation. His measurements in seawater showed conclusively that the dependence of absorption on the square of frequency was not valid in the 100-1000 kHz frequency range; he related this anomaly to a relaxation process, specifically (and incorrectly) to the chemical dissociation of NaCl. Kurtze and Tamm[6] investigated three possible mechanisms for the excess attenuation in

electrolytes. These were thermal relaxation, structural relaxation, and chemical relaxation. They attributed the observed relaxation in seawater to chemical dissociation of $MgSO_4$ rather than NaCl, specifically to the reaction $MgSO_4 \cdot H_2O \rightarrow Mg^{++} + H_2O + SO_4^{--}$. In 1956, Murphy, Garrison, and Potter[7,8] performed an in situ transmission experiment at 10°C and found the absorption to be significantly different from that predicted by Del Grosso[9] and Beyer[10] who based their theories on the results of Kurtze and Tamm[6] and of Wilson and Leonard.[11] Absorption values were extrapolated from these data to predict attenuations at various temperatures other than 10°C (see Figure 2).

In the early 1960's, Schulkin and Marsh[12,13] extended absorption measurements in the open ocean to a frequency range of 2-25 kHz and discussed the pressure, salinity and temperature dependence of the absorption at these frequencies. They proposed that the proper form of absorption versus frequency is B/f_t and fit the data of Pinkerton to this curve. Although they state that the error between theory and experiment is less than 10% (except for temperatures above 75°F), it is unclear that this treatment is valid at temperatures nearing the freezing point either for saline solutions or fresh water.

In the early 1970's, Skretting and Leroy[14] measured sound attenuation in the Western Mediterranean in the frequency range of 200 Hz to 10 kHz. They observed a variation of about 20% between their data and the results of tests in the North Atlantic in the 1-5 kHz range. They attributed this discrepancy to temperature differences between the test sites. Thus, prior to the Chukchi Sea experiments by Garrison,[15] starting in 1972 there appear to have been no direct measurements of acoustic attenuation in seawater below 0°C. The results of Garrison's tests are shown in Figure 3 along with the theoretical curve of Del Grosso and the results of the measurements by Murphy, Potter and Garrison nearly 20 years earlier. The results indicate that significant variations are to be expected, at least at the lower frequencies.

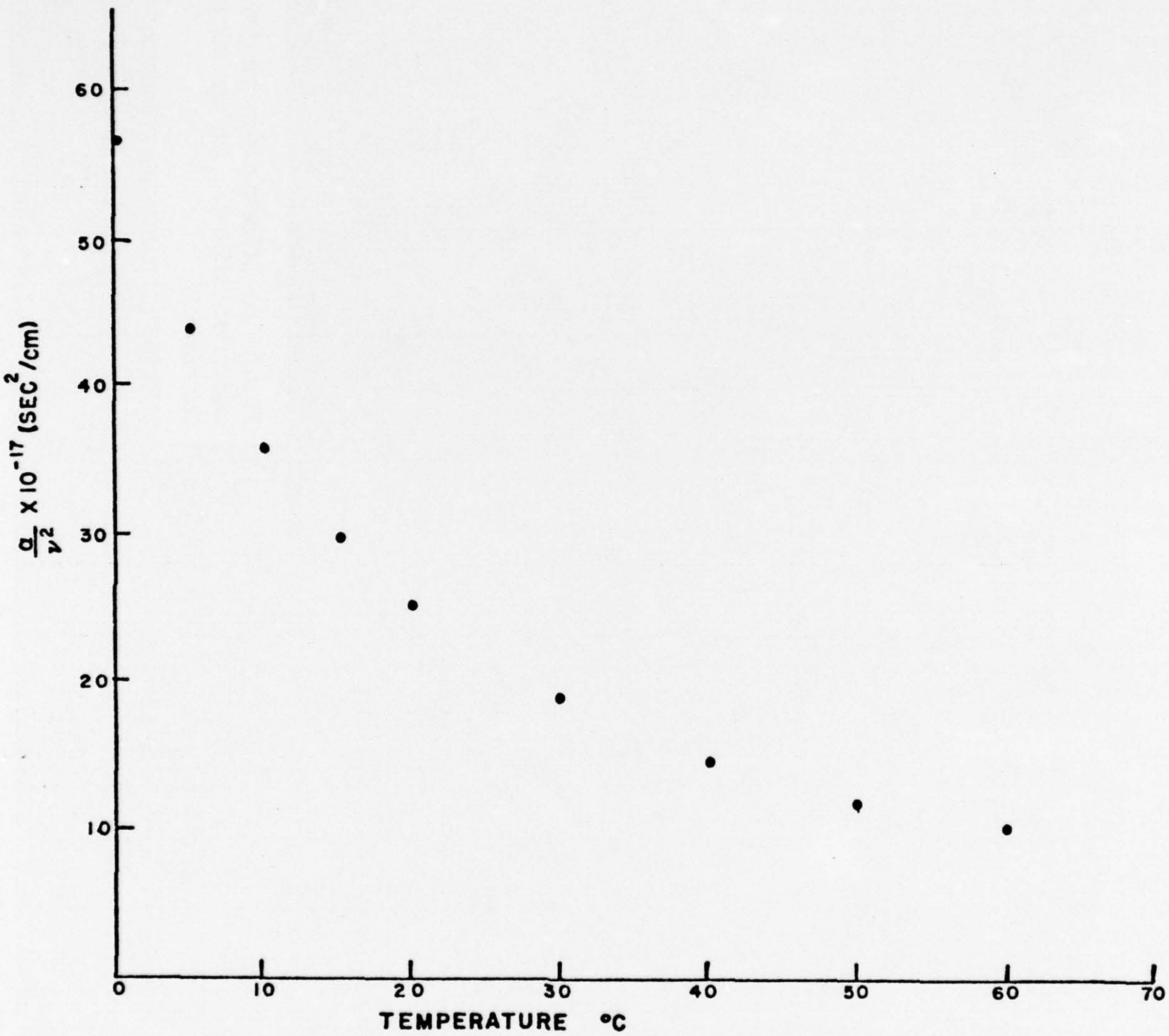


Figure 1. Absorption divided by frequency squared vs temperature. (after Pinkerton[4])

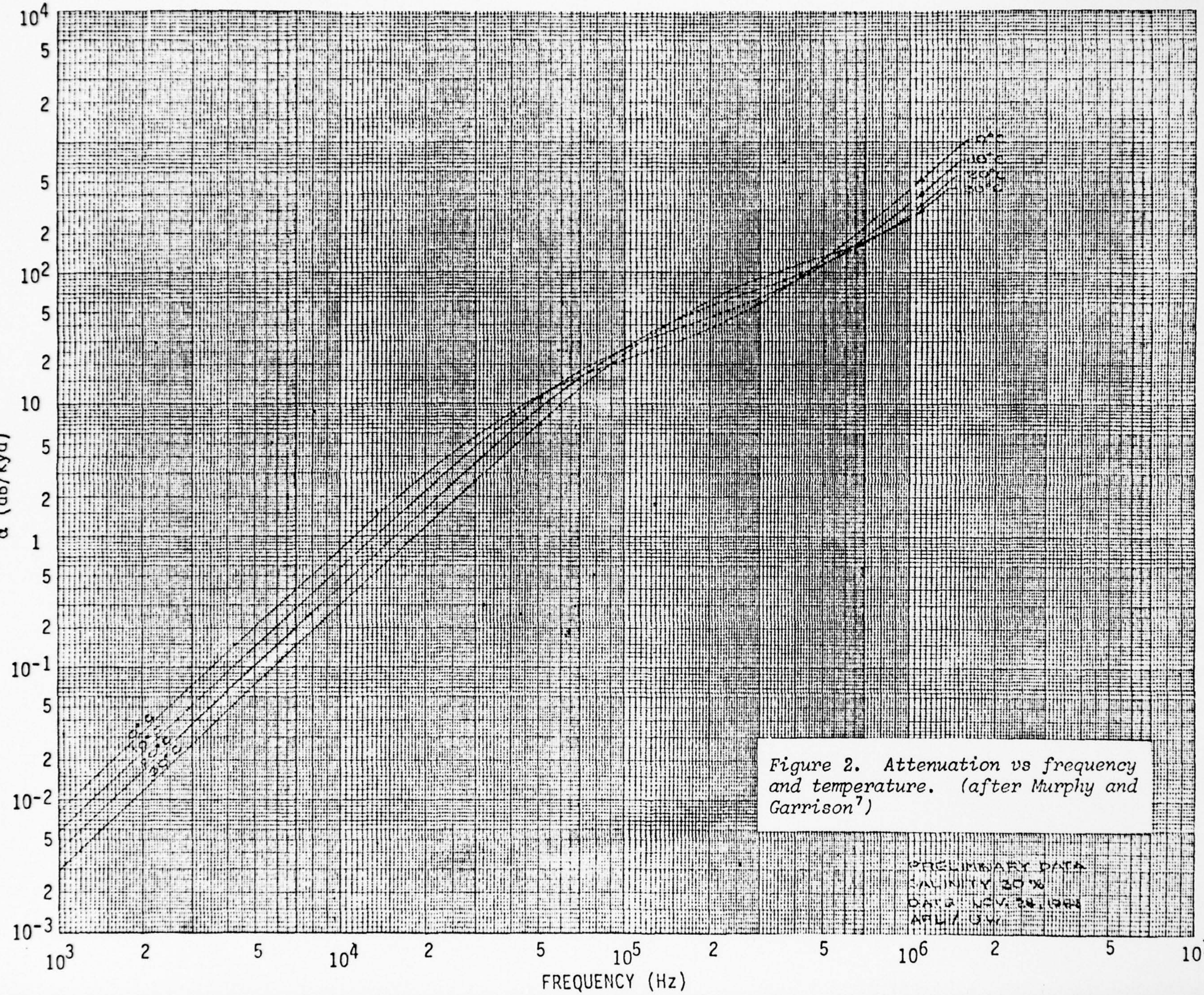


Figure 2. Attenuation vs frequency and temperature. (after Murphy and Garrison[7])

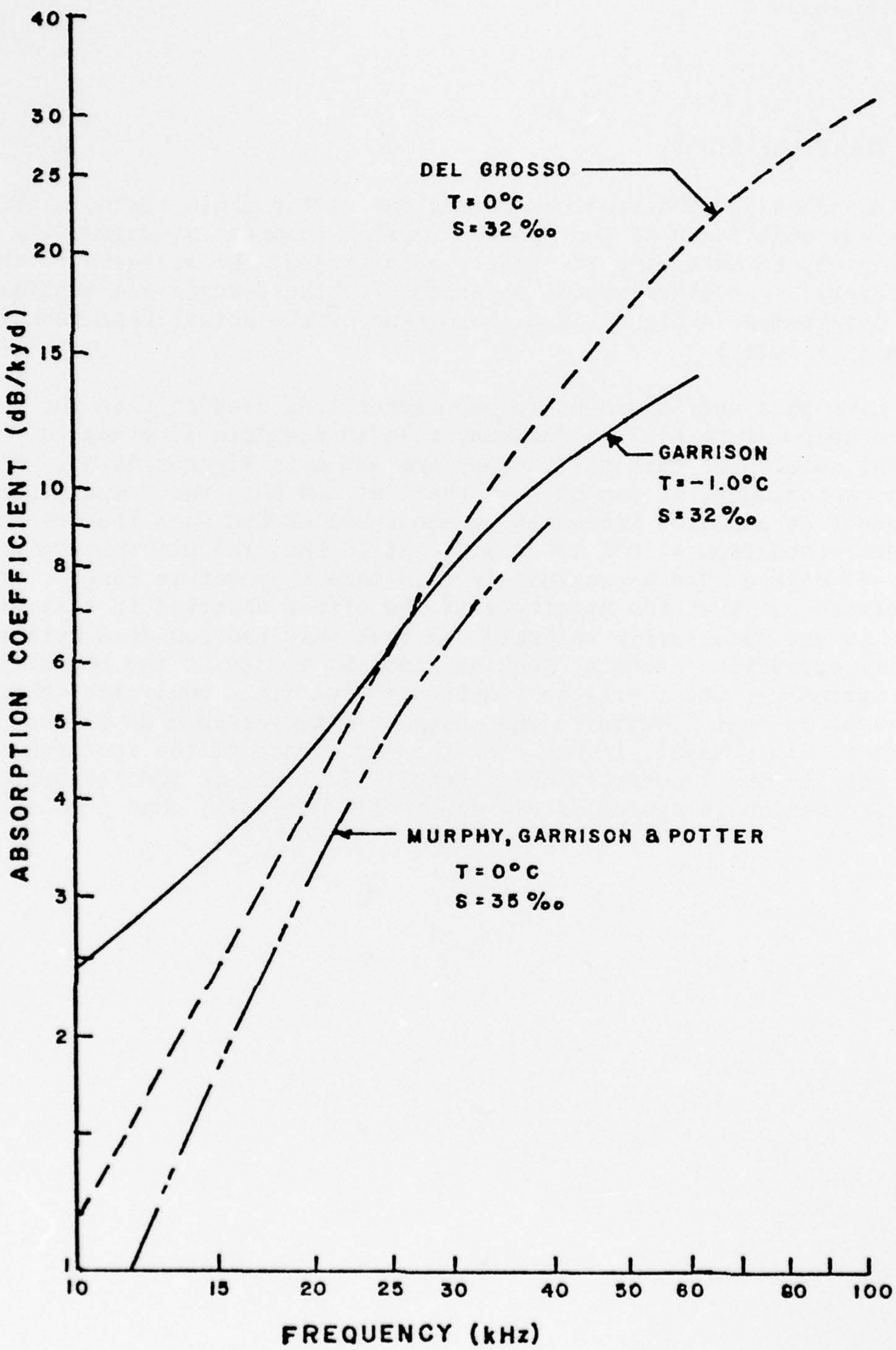


Figure 3. Attenuation vs frequency: results of Chukchi Sea tests.

III. THE PILOT STUDY

Based on the observations during the arctic field tests, a pilot study was undertaken at the Applied Physics Laboratory, University of Washington, to determine if similar results could be achieved in the laboratory. The experimental apparatus for these tests was similar to that diagrammed in Figure 4; a photograph of the actual test tank is shown in Figure 5.

Even this very rudimentary experiment indicated that in the subzero domain temperature plays a dominant role in acoustic attenuation. Typical results of this pilot study are shown in Figures 6a-6c. From these photographs, it can be seen that, at 680 kHz, the temperature-dependent attenuation increased by about 200 dB/kyd when the temperature was decreased from +1.8°C to -0.3°C. At 75 kHz, the attenuation increased by 40-45 dB/kyd over approximately this same temperature range. It should be pointed out that the magnitude of the effect observed in this pilot study is not necessarily reliable, in that only the raw data were reported. Several correction factors, such as acoustic losses at the boundaries, beam spreading, etc., will be required in the final analysis. What is important is that a definite and observable temperature dependence is apparent. In general, it has been the experience of the researchers at APL, both in the laboratory and in the field, that at low temperatures the attenuation is approximately double (in decibels) that predicted by theory.

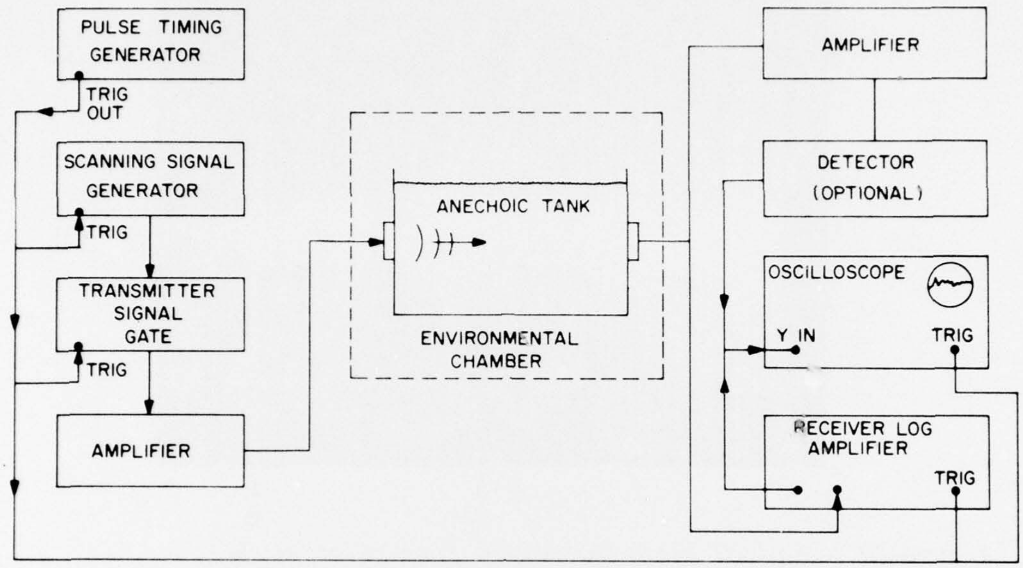


Figure 4. Block diagram of the experiment performed during the pilot study.

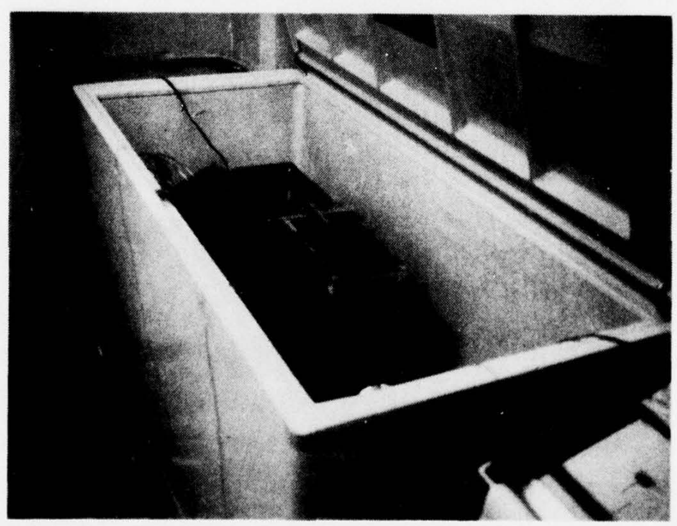


Figure 5. Photograph of test facility for pilot study.

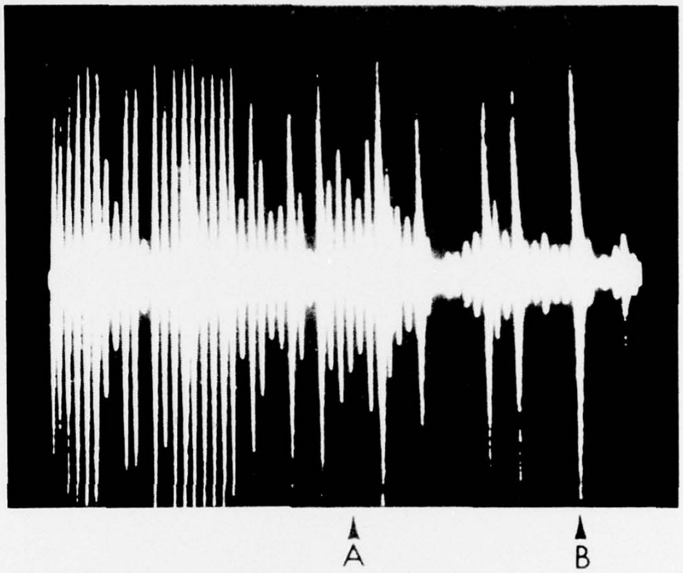


Figure 6a. *Typical acoustic return from pilot study.*
Freq. = 680.3 kHz; Sweep = 5 msec/div.
Amp. = 0.02 V/div.; Temp. = 1.84°C.
Arrow "A" represents approx. 125-ft folded path length.
Arrow "B" represents 60-cycle noise spike.

Figure 6b. *Typical acoustic return from pilot study.*
Freq. = 680.3 kHz; Sweep = 5 msec/div.;
Amp. = 0.02 V/div.; Temp. = 0.69°C.
Arrow represents approx. 125-ft folded path length.

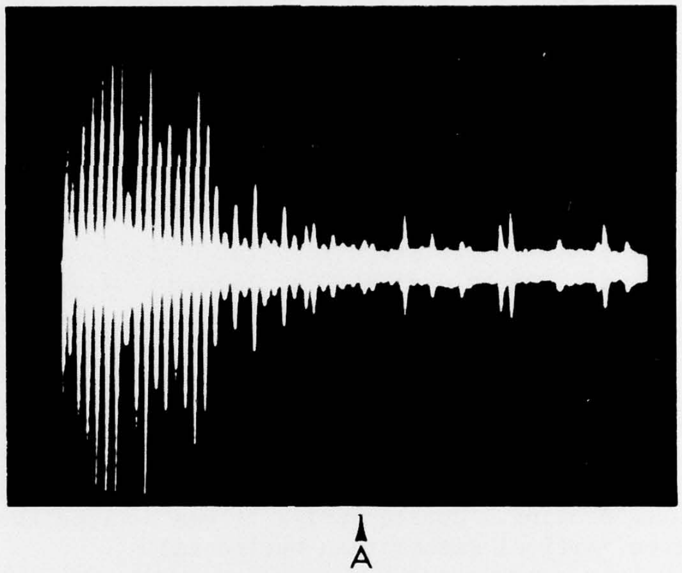


Figure 6c. *Typical acoustic return from pilot study.*
Freq. = 680.3 kHz; Sweep = 5 msec/div.
Amp. = 0.02 V/div.; Temp. = -0.3°C.
Arrow indicates approx. 125-ft folded path length.

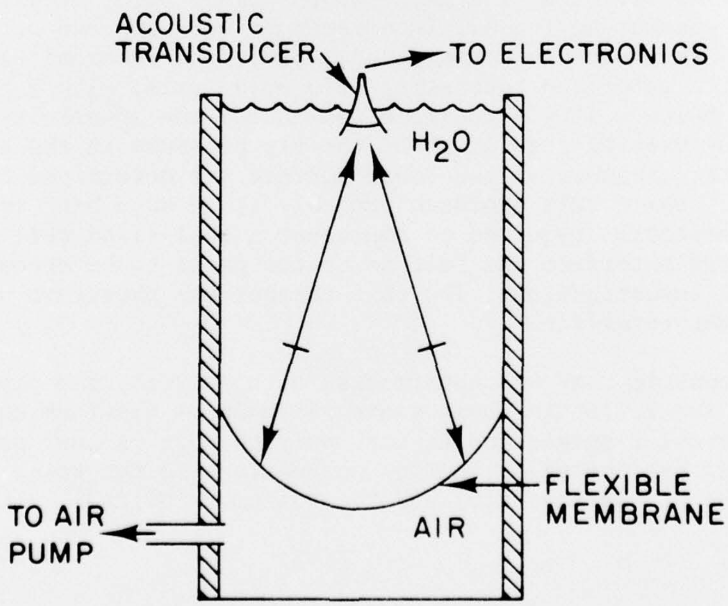


Figure 7. *Prototype vertical water cell.*

IV. DESIGN OF THE ACOUSTIC EXPERIMENT

A. Thermal Gradient Considerations

During preliminary investigations for Phase I, the pilot study equipment was utilized to evaluate the adequacy of a horizontal, folded acoustic path. It was ascertained that even minor vertical thermal gradients could cause a multiply-folded acoustic path to wander to the bottom of the acoustic chamber. While tilting the reflectors showed some promise, it became clear that, at the slow cooling rates anticipated for the experiment, nullifying the effects of the thermal gradient would require continual adjustment of the tilting reflectors and this manipulation would interfere with the thermal equilibrium during the long-term slow cooling. Consequently, it was decided that the acoustic path should be vertical rather than horizontal.

B. Acoustic Chamber Development

Focusing Vertical Water Cell Concept: The first question in the design of the vertical test chamber was whether the reflecting surfaces at each end of the folded path should be air interfaced or rigid. Because the minimal acoustic transmission through a water-air interface (and the consequent retention of more acoustic energy within the medium) would allow utilization of a much longer folded path, it was decided to try a test chamber having air interfaces at both top and bottom (see Figure 7). We therefore constructed a prototype vertical water cell with a bottom interface consisting of a mylar film, with a pressurized air cavity below. It was possible to control the sphericity of the interface by careful regulation of the air pressure in the support cavity. The curvature of the lower surface was determined by optical reflection. While this approach probably could have been made to work, the instrumentation required to implement a full-sized cell using the air-supported interface was felt to be too great to be encompassed in the Phase I investigation. The test chamber was therefore designed with a rigid lower interface.

The acoustic tank was constructed of a polyethylene pipe, 18 in. in diameter. The reflecting base plate was made of aluminum and was 3 in. thick. Thermal transmission through polyethylene is low, and it was anticipated that the major thermal connections to the water column would therefore be at the top (air) and the bottom (aluminum) interfaces.

C. Acoustic Instrumentation

Single Path Experiment: The most straightforward design for an acoustic transmission experiment is a bistatic configuration in which separate sensors are used for transmitting and receiving the acoustic signal. This bounce-free path allows the effects of the medium alone to be studied, without consideration of boundary effects. Therefore, knowing the efficiency of the transducers and the spreading losses, the attenuation can be measured directly. This was the configuration used in the initial vertical propagation tests (see Figure 8). A typical result of these tests is shown in Figure 9. The results were not only erratic but yielded values of attenuation far in excess of those known for distilled water in well-measured temperature regimes. This is not necessarily a surprising result for the following reasons.

(a) In the laboratory, the path length is short, which both contributes to near-field effects (i.e., the acoustic pulse is undergoing its maximum spreading loss) and causes small errors in the measurements to introduce significant errors in the results.

(b) The efficiency of the transmitter is not adequately known because of coupling losses into the medium, therefore a measure of the energy introduced into the medium is needed. This configuration does not allow for this measurement.

(c) Without extensive calibration procedures, the temperature dependence of the efficiency and/or sensitivities of the transducers is unknown.

Monostatic Experiment: We then switched to a monostatic configuration. In a monostatic experiment, such as shown in Figures 10a and 10b, a single acoustic transducer is used both as the projector and as the receiver. This gives a tremendous advantage in that the temperature-dependent sensitivity of the active element is normalized. This technique also allows for a longer path length using multiple reflections between the bottom of the test chamber and the water-air surface. The principal disadvantages of this technique are the inability to determine the efficiency of the transducer (in particular, the differences between the transmit and receive modes) and possible errors caused by surface disturbances. Also, at least two reflections are required to normalize the temperature dependence of the active element. This may or may not be a problem, depending on the attenuation/absorption of the medium.

Modified Monostatic Experiment: Figure 11 diagrams a modified monostatic procedure that was tried. It is similar to the monostatic experiment described earlier except that a receiving hydrophone was used

to measure the amplitude of both the transmitted pulse and the reflected pulses. This configuration has the advantage of temperature independence with respect to transducer sensitivity because all of the reflected paths are compared to the initial pulse for attenuation calculations. Also, between the first two pulses observed, i.e., the initial pulse and the first reflected pulse, no effects of air-water interface disturbances are present since the acoustic wave has not yet reached that location. (Of course, spreading effects must be considered.)

Further, provided that the bottom is thick enough and of an acoustically known material, changes of the reflecting surface with temperature can be monitored by observing changes in the multiple reflections from within the bottom layer (see Figures 12a and 12b). Any variations in this pattern are indicative of changes in the transmission and/or the reflection coefficients at that surface.

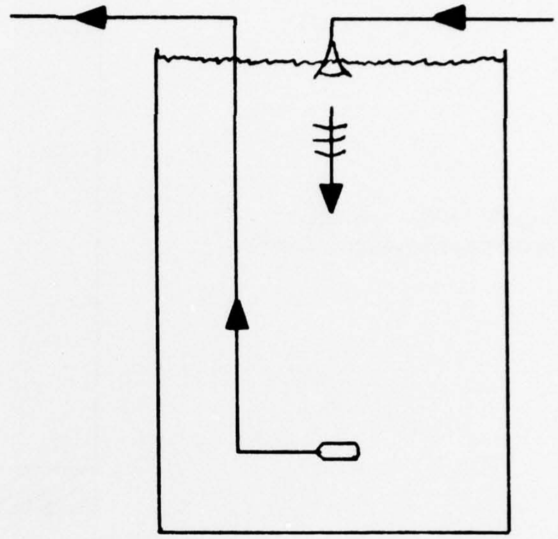


Figure 8. Diagram of the bistatic configuration.

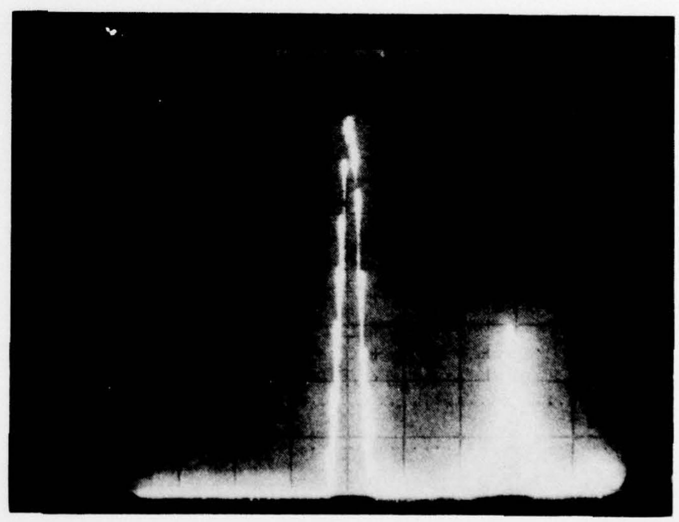


Figure 9. Typical result of bistatic configuration.

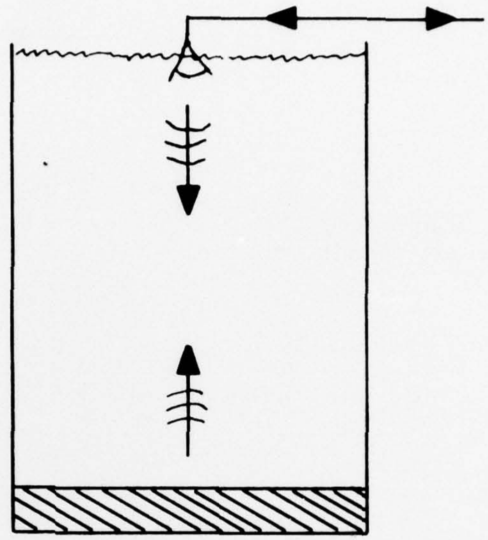


Figure 10a. Diagram of monostatic experiment.

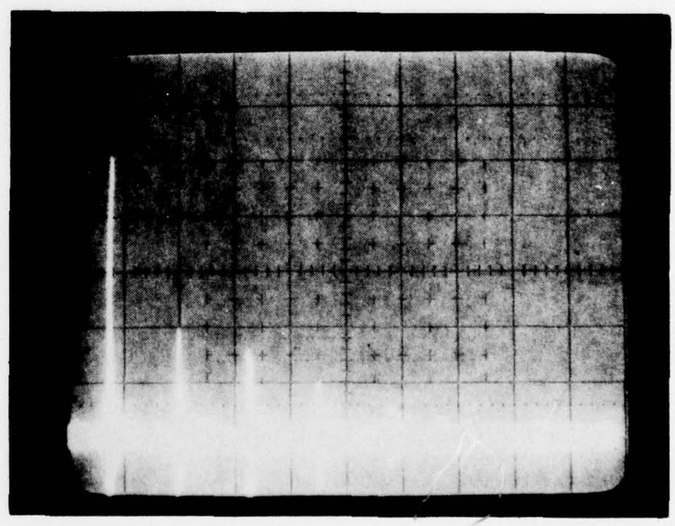


Figure 10b. Typical result of monostatic experiment.

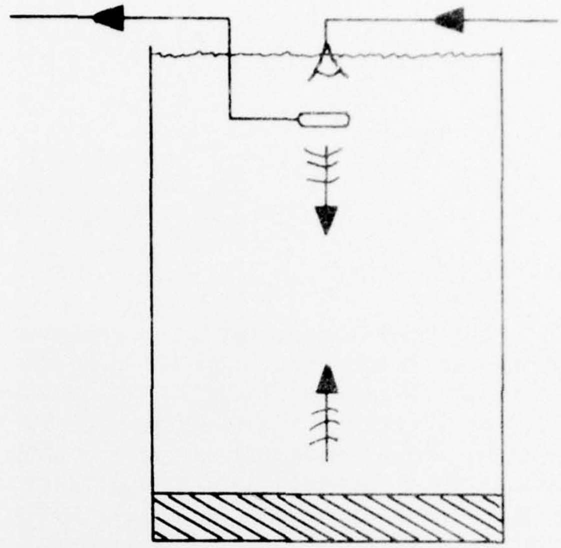
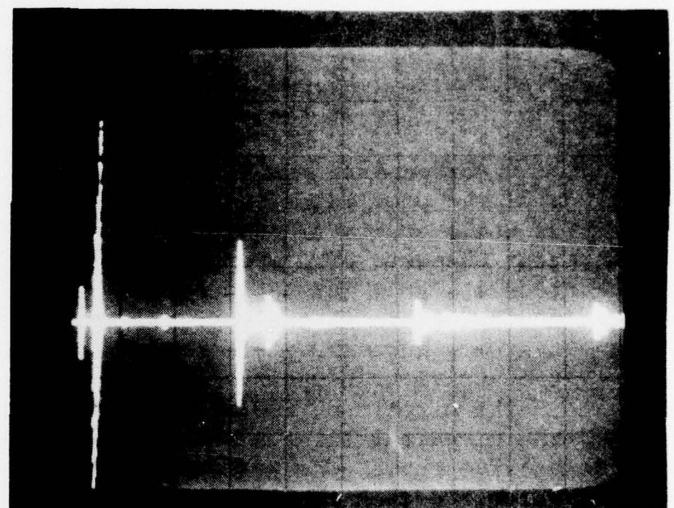


Figure 11. Diagram of the modified monostatic experiment.



A

Figure 12a. Typical result of the modified monostatic experiment.

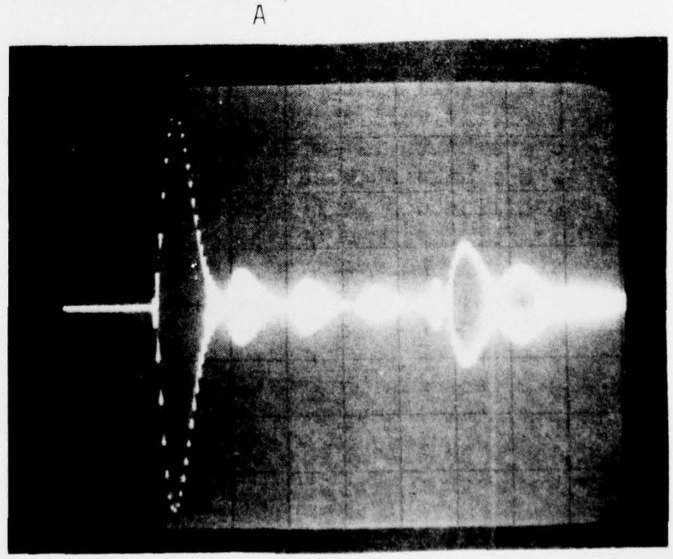


Figure 12b. Magnification of Section A, above.

V. CONCLUSIONS

The modified monostatic technique appears to be a reasonable approach to monitoring acoustic attenuation/absorption near the freezing point of saline solutions. The primary advantage of this method is the ability to change the measurement parameters (i.e., frequency, pulse length, propagation path, etc.) without greatly modifying the experiment. This capability is not present in other laboratory methods, such as the resonant cavity, that are often used to measure relaxation phenomena. Further, the method allows for a long folded path and constant monitoring of the reflecting surface.

The recommended acoustic experiment is shown in Figure 13. The experimental instrumentation is composed of three subsystems: (a) active electronics, (b) passive electronics, and (c) environmental conditioning. The functions of these subsystems are as follows:

Active Electronics: A cw pulse of appropriate length is formed by a pulsed oscillator (a signal generator and an electronic gate will work as well) and is transmitted to the acoustic transducer located in the test chamber. The piezoelectric transducer then converts this electronic signal into an acoustic pulse and projects it into the liquid medium. This is the basic instrumentation required of the active subsystem. However, it is convenient to monitor changes that may occur in the active transducer. Therefore, a transmit-receive switch is placed in the circuit to isolate the pulse-forming electronics from the rest of the circuit until the next pulse is ready to be initiated. During this passive phase, the transducer monitors all returning acoustic signals, which are then amplified and displayed on an oscilloscope.

Passive Electronics: A small, high-resolution, wide-band hydrophone is placed in the path of the acoustic signal generated by the active system. This hydrophone will sense the acoustic disturbance on the initial pass, as well as multiple reflections (see Figure 12b). The detected disturbance is amplified and displayed on both an analog oscilloscope and a high-speed digital storage oscilloscope. The purpose of the first oscilloscope is for monitoring the experiment while that of the second is for data reduction. The digital oscilloscope has the capability of storing the received signal and processing it for comparative analysis.

Environmental Conditioning: This is perhaps the most critical portion of the entire experiment. Experience has shown that temperature gradients in the test facility not only lead to inaccuracies in the experimental measurements but also tend to cause circulation in the test liquid. Near the freezing point, this circulation is undesirable because

the solution becomes unstable. Therefore, the experiment must be performed in an environmental chamber in which the temperature is uniform throughout to within at least 0.1°C. Further, since the entire temperature range of interest is less than 3°, the ambient temperature in the environmental chamber should be controllable to within 0.2°C or less.

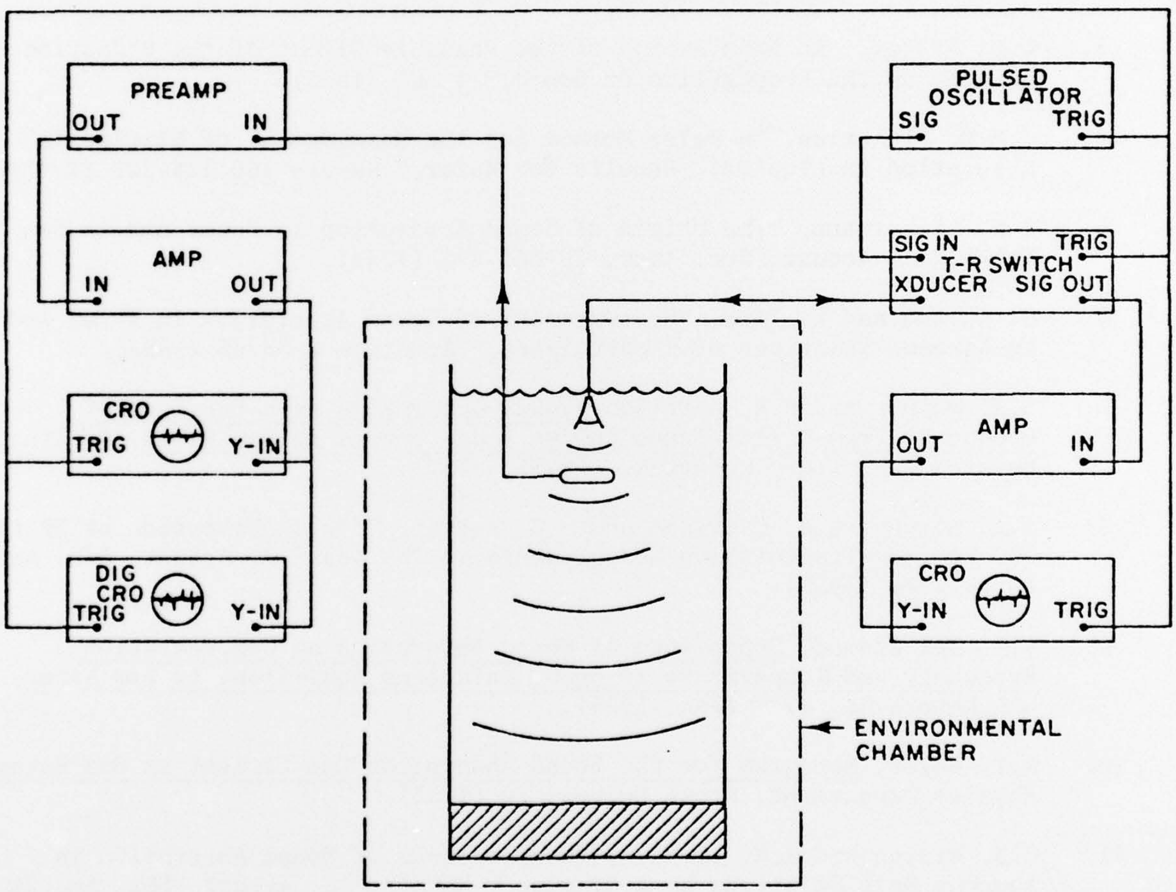


Figure 13. Recommended experiment.

X. REFERENCES

1. E. Pence, personal communication.

2. G.G. Stokes, "On the Theories of the Internal Friction of Fluids in Motion and of the Equilibrium and Motion of Elastic Solids," Trans. Camb. Phil. Soc. 8 287 (1845).

3. G.G. Stokes, "An Examination of the Possible Effect of the Radiation of Heat on the Propagation of Sound," 1 305 (1851).

4. J.M.M. Pinkerton, "A Pulse Method for the Measurement of Ultrasonic Absorption in Liquids: Results for Water," Nature 160 128-129 (1947).

5. L.N. Liebermann, "The Origin of Sound Absorption in Water and in Sea Water," J. Acoust. Soc. Amer. 20 868-873 (1948).

6. G. Kurtze and K. Tamm, "Measurements of Sound Absorption in Water and in Aqueous Solutions of Electrolytes," Acustica 3 33-48 (1953).

7. S.R. Murphy and G.R. Garrison, Sound Absorption as a Function of Frequency from Direct Transmission Measurements in Sea Water, Applied Physics Laboratory Report No. 56-35 (1957).

8. S.R. Murphy, G.R. Garrison and D.S. Potter, "Sound Absorption at 50 to 500 kc from Transmission Measurements in the Sea," J. Acoust. Soc. Amer. 30 871-875 (1958).

9. V.A. Del Grosso, Dependence of Sound Absorption on Concentration Frequency and Temperature in $MgSO_4$ Solutions Equivalent to Sea Water, NRL Report No. 4279 (Jan. 1954).

10. R.T. Beyer, Nomogram for the Sound Absorption Coefficient in Sea Water, Physics Department, Brown University (1953).

11. O.B. Wilson and R.W. Leonard, "Measurements of Sound Absorption in Aqueous Salt Solutions by a Resonator Method," J. Acoust. Soc. Am. 26 223-226 (1954).

12. M. Schulkin and H.W. Marsh, "Sound Absorption in Sea Water," J. Acoust. Soc. Amer. 36 864-865 L (1962).

13. M. Schulkin and H.W. Marsh, "Absorption of Sound in Sea Water," J. Brit. I.R.E. 25 493-500 (June 1963).

14. A. Skretting and C.C. Leroy, "Sound Attenuation Between 200 Hz and 10 kHz," J. Acoust. Soc. Amer. 49 276-281 (1971).

15. G.R. Garrison, personal communication of unpublished data.